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Towards implementation of DfRem into the product development process

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Abstract

Design for Remanufacturing (DfRem) is one of the key issues for companies which are engaging in or planning to go into remanufacturing. Successful integration of DfRem within the existing product development process requires not only the availability of appropriate design tools, but also the various forms of support within the business operations. However, thus far, there has not been any research that addresses the perspective of both. Therefore, a holistic approach, covering both the strategic level (what to do) and the tactical level (how to do), is presented in this paper to assist decision makers to take timely strategic actions as well as to select the appropriate DfRem tools, so as to promote effective and efficient remanufacturing implementation throughout product development stages. The strategic actions, such as cross functional communications, management support, and the DfRem tools, including platform design, DfRem checklist etc., are reviewed and classified according to the stages of the product development process where they can have the maximum impact on, so as to provide an orderly integrative process.

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Keywords: Remanufacturing; Design for Remanufacturing; Integration of DfRem

1. Introduction

Remanufacturing, one of the sustainable manufacturing strategies, has gained growing popularity during the past few decades due to its effectiveness in preserving component intrinsic values as well as assuring the quality of the reprocessed products. It is the process of bringing products back to sound working status, through disassembly, sorting, inspection, cleaning, reconditioning and reassembly processes [1]. Previous research has indicated that many barriers in remanufacturing processes are closely related to the product design stage, and this has ignited the concept of 'Design for Remanufacturing (DfRem)' as a much pursued design activity [2]. Design for Remanufacturing implies actions to be taken during the product development stage to enhance the remanufacturing efficiency of a product without compromising other essential product characteristics, such as cost and performance. It is practical and realistic to adapt DfRem to existing product development strategies rather than to expect an original product design model to take drastic change to accommodate DfRem [3]. Even though a wide range of DfRem tools and techniques has been developed to facilitate the integration of remanufacturing requirements into product development, most of them consider remanufacturing design in an isolated way, without considering the linking of the remanufacturing design with the original product development process. Furthermore, successful integration of DfRem within the existing product development process requires not only the availability of appropriate design tools, but also various forms of support from business operations. The reason is that many decisions about remanufacturing need to be made at levels well beyond the decision sphere of engineering designers. Therefore, generating an approach which covers the perspectives of both is critical so as to promote an effective and efficient remanufacturing implementation. This article reviews the strategic factors and design tools that assist product design for remanufacturing. Next, an approach is proposed based on the taxonomy of strategic activities and design tools, aiming to assist decision makers to take timely strategic actions and select the appropriate DfRem tool(s) at the respective design stages.

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2. Literature review

The concept of DfRem needs to be addressed throughout product development so as to alleviate the difficulty encountered during the remanufacturing processes. For example, product design should avoid protruding structures in order to facilitate stacking during transportation [4]; number of fasteners and joints need to be minimized and accessibility to those fasteners and joints needs to be improved. [5]; product should be safe to inspect [6]; surfaces to be cleaned should be wear resistant and smooth such that the cleaning cost can be reduced [2]; and durable products with bulky over-design components are preferred over less material-intensive products for the sake of easy reconditioning [7]. Various design tools and methodologies have been proposed to facilitate the integration of these remanufacturing considerations into product design and many of these design tools have been developed in the forms of guidelines/checklist, quantitative and qualitative assessment metrics, life cycle based evaluation tools as well as based on modifications of existing product design tools [4, 8, 9, 10, 11, 12]. Even though there is an increasing amount of work on developing DfRem tools, most of them consider remanufacturing in an isolated manner, without investigating the link with the original product development process, which has, to some extent, limited their applications in practice.

DfRem is not only a technical task to be handled by individual product designers, but also a strategic move that requires support from various company departments. The reason is that many decisions about remanufacturing need to be made at levels well beyond the decision sphere of engineering designers. For example, the decision made to shift the business strategy from "selling a product" to "selling a service", implies that products are owned by manufacturers instead of customers. The manufacturers could take back the product at any appropriate time for remanufacturing or upgrading. It is evident that this strategy change would require company level support and management, since it involves redesign of both product and supply chains [13]. In addition, management support, customers' demand, cross-functional communication, education and training for designers, etc., have also been identified to be critical for integrating DfRem into the existing product design stage [3, 14, 15]. However, simply listing out all the strategic factors is of limited value to the industry [16]. A discussion on the method to address these strategic factors along product development process would be more useful for DfRem integration. A generic design process (Figure 1) usually consists of three sequential stages, namely, task identification and prioritization stage, product conceptual, embodiment and detailed design stage and design evaluation stage, which the development team must iterate and follow closely [17]. To integrate DfRem into each of these product development processes systematically, the authors have proposed a process-centred approach. Both strategic activities and suggested design tools will be included in this approach, in order to present a holistic framework on the "what to do" and "how to do" for an effective and efficient remanufacturing integration.

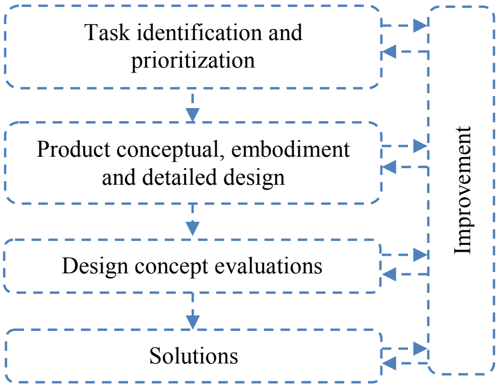

Fig. 1. Generic design process

3. Approach for holistic DfRem integration

The details of the approach for implementing DfRem along the product development process will be presented in this section. In this approach, as shown in Figure 2, the strategic factors are organized based on the design phases in which they have the most influence on; the tactical DfRem tools are classified according to the type of information they required and the decisions they can provide.

Stage 1: Task identification and prioritization

In the task identification and prioritization stage, the design team clarifies the design targets to be achieved by considering various requirements, such as customer demand, legislation, environmental concern, technology trend, and cost. The importance of these requirements is usually assigned based on company business decision and priority. It is critical to weigh in the remanufacturing considerations at this stage when the freedom of design is maximum.

- **Strategic activities**

From strategic point of view, several activities are essential for integrating DfRem at this stage. The first activity is to investigate customer demand and market competitiveness for remanufactured products. Sufficient customer demand is always the kick-start factor for integrating DfRem into product development. The markets for low cost spare parts, "green consumers", "product service business system", etc., are all the potential types of markets for remanufactured products [18]. The requirements identified through these market investigations should be considered as the forefront of the product design specifications. The second activity is to identify the barriers in remanufacturing processes. There is often a lack of communication between product designers and remanufacturers on the impacts (positive or negative) of certain design features on the remanufacturing process and this has most of the time, resulted in wasted effort during

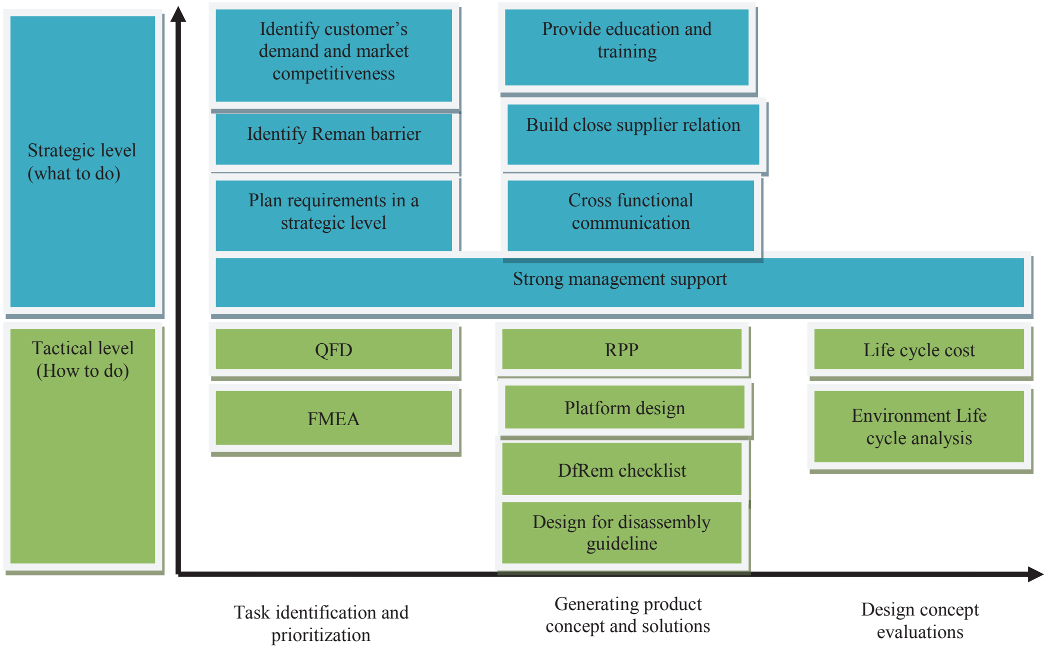

Figure 2: the proposed guideline for integrating DfRem into product development process

product remanufacturing [15]. Therefore, effective communications between remanufacturers and OEM design engineers need to be encouraged, so that designers can stay informed of the difficulty of the remanufacturing processes and ease these problems through proper product design. The next activity is to determine the indicators performance carefully for product remanufacturability, such as successful remanufacturing rate, reprocessing cost, etc., and synthesize these factors with existing product performance indicators, e.g., product life time and profit. In this way, DfRem factors are addressed not only at the operational level, but also down to the strategic level [19, 20, 21]. Last but not least, having support from management team for initiating the DfRem activities is always indispensable, as it is the management who will oversee integration and set the goals of product development.

- **Tactical design approaches**

Among the DfRem methodologies and tools that have been proposed, the Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD) have been identified to be effective for DfRem task identification and prioritization [22, 23]. The traditional FMEA has been modified by Sherwood and Shu [24] to systematically study the waste stream of an automotive remanufacturer so as to reveal the difficulties in remanufacturing and ensure that no significant remanufacturing issues are overlooked in the new product development. Similarity, QFD, which is a technique originally developed for identifying customer's demand, has subsequently been reinterpreted for remanufacturing to improve the communication between remanufactures and designers. To apply QFD for DfRem, the "voice of customers" will come from the remanufacturers' feedback and the "engineering attributes" will refer to the design parameters that can improve the remanufacturability of the products. The output of this methodology will be the prioritization of each engineering attribute with respect to remanufacturability enhancement. Thus, QFD can function like a bridge to translate the abstract remanufacturing feedback to concrete design attributes for design improvement. The applicability of QFD in prioritizing the task of DfRem has been demonstrated by Yang et al. [10].

Stage 2: Generating product concept and solution

After design objectives have been defined, it is necessary to develop the design ideas and preliminary concepts (conceptual design), produce a detailed description of product layout (embodiment design) and develop a complete design solution (detailed design). These three stages are not in a rigidly sequential order, but largely simultaneous [25].

- **Strategic activities**

To promote the intervention oriented towards remanufacturing aspects, the following strategic activities should be carried out.

Firstly, to provide education and training for product designers. Proper education and training can help grow the mind-set that DfRem should be considered during the design stage among designers [3, 26, 27]. Training and education can be carried out through organizing plant visits to remanufacturing sites, workshop on remanufacturing-related design tools, and seminars for introducing remanufacturing design guidelines or difficulty that remanufacturers have encountered [28, 29].

Secondly, to gain management support for DfRem. A strong senior management support not only can garner strong financial backing for the project [16], but also help recruit remanufacturing experts who can advise the team on the impact of design alternatives on remanufacturing efficiency or even constantly inspire the design team to consider DfRem issues [30].

Thirdly, to build close suppliers relationships. It is unlikely that OEMs are responsible for producing all the components of their products, and therefore the expertise of suppliers in the out-sourced components can be a valuable input while designers are searching for product design that is beneficial for remanufacturing [16, 31].

Fourthly, to promote cross-functional communication. As design involves various aspects of considerations, such as productivity, aesthetics, cost, environmental performance, functional performance and especially remanufacturability in this context, having effective communications and collaborations among different teams is acute. The forms of cross-functional communications can include sharing of data and information or constantly obtaining feedback from different design teams. Even though under most of the circumstances, remanufacturing is not a top design priority [3], the presence of remanufacturing requirements at this stage is critical for ensuring that remanufacturing concerns are not neglected [32]. In addition, frequent external communication with remanufacturing site can help expose the project team to new information, e.g., latest remanufacturing technology, which can impact the way that designers design the product [16].

- **Tactical design approaches**

Various design tools and approaches have been proposed and are found to be useful for facilitating product conceptual and detailed design for remanufacturing. One of the examples is Remanufacturing Product Profiles (RPP) reported by Zwolinski et al. [11]. RPP encapsulates the knowledge of both remanufacturing context and remanufactured product properties. A quantitative assessment of the product properties would be made to guide product designers towards an existing product profile which properties are well-adapted to remanufacturing. Meanwhile, platform design, aiming to accommodate a product for final End of Life (EOL) strategies, has also been identified to be useful for improving product remanufacturability at the conceptual design stage. To apply this methodology, potential multiple life components will form the base platform and single life components will form the parametric components. The effectiveness of this methodology has been demonstrated through an electro-mechanical product design. Further, the use of DfRem checklists, with its easiness of application, has been found to be effective for enforcing DfRem considerations into the product detailed design stage. Checklists refer to sets of criteria to be considered to identify the opportunity for remanufacturing enhancement and setting up goals to be achieved, such as "reducing the number of the fasteners for easy disassembly", "increasing surface wear resistance", "making all the similar parts being clearly identified and so forth", etc. Comprehensive checklists for DfRem could be found from [33, 34]. In addition, many researchers have proposed methodologies to assess the disassemblability of a product and provide improvement suggestions to ease the product disassembly process. Examples of these tools can be referred to [35, 36, 37, 38].

Stage 3: Design solution evaluation

- **Strategic activities**

Design solution evaluation stage is the last stage to ensure remanufacturing requirements are implemented in product design and to alter design before final implementation. At this stage, the design concept is usually evaluated from various aspects, such as economic profit, environmental impact, and remanufacturability, by using the indicators established in the task identification and prioritization stage. Therefore, having management support for remanufacturing at this stage is critical to ensure that remanufacturing considerations are properly weighed in, as comparing with other design issues [3].

- **Tactical design approaches**

Several DfRem tools can be adopted at this stage, for evaluating the impact of remanufacturing design on other performance aspects and to achieve a global optimized solution. The detailed product design information which has been defined from previous phases allows the use of some life-cycle based simulation tools for design evaluation, such as Life Cycle Assessment (LCA), and Life Cycle Cost Analysis (LCC) [39, 40]. These life-cycle based simulation tools can address the conflict between remanufacturing with other design issues and provide a quantitative account of the trade-off among all the constraints. For example, Shu and Flowers [4] have developed a framework for product fasteners and joints selections. The impact of fasteners or joints selection on remanufacturing stage relative to other life cycle stages was estimated through a LCC assessment, which provided quantitative and straightforward feedback for decision makers to make the final selection. The advantages of adopting these existing life cycle evaluation tools is the familiarity that product designers already have with them and thus allows for easy implementation of remanufacturing evaluation in this stage.

4. Discussion on the proposed approach

A holistic approach that a company and its development team can consider to implement DfRem into the original product development process is presented in this research. Both strategic activities and tactical DfRem tools are summarized and classified based on the relevance they have on the product development processes. By formulating this approach, the authors endeavour to formulate a holistic DfRem implementation that can be used in practice to promote more effective remanufacturing development. It is noted that a full-scale treatment of all the strategic actives and design for remanufacturing tools is simply beyond the scope of this work and will require further investigation. Instead, this work should be regarded as an attempt to unveil and illustrate the major aspects of the primary remanufacturing integration issue.

Various research teams have embarked on the investigation of the factors that lead to successful product development. As summarized by Pahl and Beitz [41], these factors generally included market, customer, senior management, project leader, communication, team organization, team composition, supplier involvement and tool developments. The understanding of these strategic factors can provide a solid foundation for investigating the approach to integrate DfRem into product development. Comparing the factors that affect the product development process and the factors that influence the integration of DfRem, it can be observed that those factors that are important for product development also have great impact on DfRem integration, such as customer, market, management support, close supplier relationship, and cross function design. This implies the likelihood that the integration of DfRem can be high when a company's product development management is successful. However, there are some unique factors that affect DfRem integration, e.g., the identification of special requirements from the remanufacturing sites, and the education and training of product developers for DfRem, which a company would need to pay special attention to, if integration of DfRem is to be carried out.

The proposed approach for the integration of DfRem is from a high abstract level. Given the fact that product development procedures vary among companies and product types, the selection of the DfRem tools would very much depend on the needs of the company as well as the information and skill sets that are available during the design process. For example, a company may refer to the proposed approach and choose QFD as an approach to enhance the communications between remanufacturers and product designers at its early design stage, whiles other companies, such as a large OEM which has well documented waste stream data, may want to carry out FMEA to identify the product failure reasons for remanufacturing and consequently address those issues in new product design. Therefore, detailed prescriptive procedure for DfRem integration still needs to be tailored to specific company situation.

Moreover, most of the time, DfRem is viewed to be under the umbrella of Design for Environment (DfE). Compared with DfE, DfRem is a relatively new and unexplored research area. The literature on DfE integration with the original product development process, thus, provides a valuable insight on the approaches that are likely to be applicable in DfRem integration [13, 23, 42, 43, 44]. For example, DfE literature emphasises the importance of early integration of environmental requirements, the positive impact from management commitment, and the indispensability of tools to address the environmental requirements, which inspires and concurs with the findings from successful DfRem implementation. However, DfE and DfRem are not interchangeable and sometimes, they are even in conflict with each other. For example, DfRem may require components to be over-designed such that in subsequent remanufacturing operations, e.g., machining and grinding, can be performed easily; on the other hand, DfE may require components to be designed with minimum use of materials so as not to waste resources. The difference between them emphasises the importance of exploring DfRem integration as a stand-along entity.

5. Conclusion

A holistic approach, covering both the strategic level (what to do) and the tactical level (how to do), is presented in this paper to assist decision makers to take timely strategic actions and select the appropriate design tools for remanufacturing integration. The proposed approach is design process-centred, aiming to systematically "link" DfRem with each of the product development processes, which, to authors' knowledge, is the research area that hasn't been investigated before, but is of vital importance to realize a successful product design for remanufacturing. By referring to the proposed approach, those companies which are engaging in or planning to go into remanufacturing can understand the major primary remanufacturing integration issues and thus better implement or prepare for designing product for remanufacturing.

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